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## *Research article*

# Efficacy of Preharvest Calcium Chloride and Calcium Gluconate Treatments on the Postharvest Quality Maintenance of Marian Plums During Shelf Life

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## Abstract

Marian plum is a commercial fruit that deteriorates rapidly during storage. The effects of preharvest treatment with calcium chloride ($CaCl_2$) and calcium gluconate (CaGlu) at two concentrations (1 and 2%) on maintaining the postharvest quality of marian plum during shelf life at 26±2ºC were investigated. The fruits were sprayed with both calcium salts 2 days prior to harvest. The outcomes show that both the $CaCl_2$ and CaGlu treatments preserved fruit visual appearance and postponed color development during shelf life. No fruit rot incidence appeared on the 2% $CaCl_2$ and 2% CaGlu treated fruits during storage for 8 days. All calcium treatments retarded the increase in weight loss compared to the untreated fruits. The fruit firmness was maintained by the calcium treatments, and 2% CaGlu treatments improved the firmness greater than other treatments. Moreover, the increases in malondialdehyde (MDA), total soluble solids (TSS) and BrimA, as well as the decreased total acidity (TA) were lowered by the calcium treatments. The total phenols and antioxidant capacities, including ferric reducing antioxidant power (FRAP) and DPPH free radical scavenging activity, were enhanced by the calcium treatments. In correlation analysis, the firmness showed significantly negative correlation with MDA and parameters related to ripening. Moreover, the MDA had significant negative correlation with DPPH radical scavenging activity. The softening of the marian plum was closely related to membrane degradation. Both preharvest CaGlu and $CaCl_2$ treatments at 2% are feasible approaches to preserve the postharvest quality of marian plums during shelf life at room temperature.

**Keywords:** marian plum; calcium chloride; calcium gluconate; postharvest quality

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## 1. Introduction

Marian plum (*Bouea burmanica* Griff.), a non-climacteric tropical fruit, is widely grown in Southeast Asia (Posom et al., 2020). The demand for marian plums within the domestic markets in Thailand and for export has grown, and its market value remains elevated. However, the short shelf life of marian plums, resulting from softening, fungal infections, wrinkling, and jelly flesh, limits their trade (Watanadumrong & Chemsripong, 2021). The thin and delicate skin of marian plums is susceptible to damage during harvesting, transportation, and storage. Such damage increases the risk of pathogenic microbial invasion, further accelerating fruit deterioration. Marian plums require harvesting at the ripening stage due to their short harvesting period. The primary element influencing fruit texture is the stage of harvest. Harvesting the fruit too ripe results in its sluggishness and the transformation of the flesh into jelly around the seed (Wattanakeeboot & Chanasut, 2021). Pectin hydrolases, such as polygalacturonase (PG) and pectin methyl esterase (PME), are widely recognized as key enzymes influencing fruit texture during ripening (Nunes et al., 2009) and contributing to plum jelly seed disorder. Enzymes alter the composition and structure of cell wall polysaccharides such as cellulose and pectic polysaccharides, causing them to partially dissolve (Waldron et al., 1997). Marian plums typically have a shelf life of approximately 4 days at room temperature (RT) in domestic and retail markets. According to our observations, marian plums become softening, wrinkling, and decaying within 6-7 days after harvest when stored under ambient conditions. Moreover, postharvest marian plums are susceptible to fungal infection leading to decay and shortening of shelf life (Droby et al., 2011).

Calcium (Ca) is a critical secondary nutrient in plant physiology and plays a pivotal role in maintaining fruit quality during the postharvest period. It is widely recognized that Ca not only strengthens cell wall structure by binding pectins, but also plays a key role in regulating protein kinase signaling (Gilroy et al., 1987), increasing membrane integrity, and retarding membrane lipid peroxidation in plants (Kukura et al., 1998; Picchioni et al., 1998). Ca strengthens cell walls by cross-linking pectins in the middle lamella, thereby enhancing cell wall integrity and reducing enzymatic degradation (Hepler & Winship, 2010). Ca also keeps cell membranes stable; it lowers permeability and stops water and ions from leaking out. These effects work together to keep fruit firm, delay ripening, and lower decay (Balantič et al., 2022). Several studies have demonstrated the effectiveness of preharvest Ca treatments in improving the postharvest quality of fruits. Shehata et al. (2021) investigated the extension of shelf life and maintenance of the quality of tomato fruit using $CaCl_2$. Gao et al. (2019) reported that papaya fruit yellowing was delayed by 4 days in 2.5% $CaCl_2$-treated fruits compared with control. Mazumder et al. (2021) suggested that tomato fruit in the mature green stage treated with 2% $CaCl_2$ had significantly lower ethylene production, weight loss, and color development. According to Guo et al. (2023), $CaCl_2$ made the cell wall structure stronger and slowed down the browning of the peel by enzymes, the softening of the pulp, and the start of diseases that happen when lychee fruits are stored. Compared to inorganic calcium salts like $CaCl_2$, CaGlu releases calcium ions more slowly, which helps reduce the risk of phytotoxicity and surface damage to fruits. This property is particularly beneficial for fruits with thin skins (Akhtar & Rab, 2014). Mona et al. (2024) reported that the combined application of CaGlu and sanitizing agents such as hydrogen peroxide significantly reduced weight loss and decay in cantaloupe, while maintaining firmness and overall appearance during 28 days of storage at 5°C. Akhtar and Rab (2014) demonstrated that a 1.5% CaGlu treatment extended the shelf life of strawberries for up to 10 days, maintained higher firmness, and resulted in the least weight loss compared to

other calcium sources. Moreoever, previous studies suggested that CaGlu might yield better results than $CaCl_2$ (Supapvanich et al., 2021; Supapvanich et al., 2024). Supapvanich et al. (2022) conducted peduncle infiltration treatments with 2% $CaCl_2$ or 2% CaGlu for 48 h to alleviate chilling injury. They suggested that both $CaCl_2$ and CaGlu alleviated chilling injury in 'Queen' pineapple and the activities of browning enzymes such as phenylalanine ammonia-lyase and polyphenol oxidase. However, CaGlu treatment proved more effective than $CaCl_2$ in alleviating the intensity and severity of internal browning (IB). According to Erbaş et al. (2023), treating sweet cherries with CaGlu slowed down the loss of titratable acidity, fruit softening, decay rate, and changes in organoleptic while they were being stored.

Thus, the effectiveness of $CaCl_2$ and CaGlu on maintaining the postharvest quality of marian plums during shelf life in an ambient environment through preharvest spraying was examined. Practically, the outcomes provide evidence-based recommendations for growers and supply chain stakeholders to implement Ca-based treatments, thereby reducing postharvest losses, improving fruit quality, and enhancing the economic value of marian plum in both local and international markets. Although calcium has been widely studied in postharvest treatments of fruits, to date there have been no reports on the use of calcium chloride and calcium gluconate in marian plum, nor any studies comparing their effects. This study aims to fill that gap.

## 2. Materials and Methods

### 2.1 Plant materials and experiment

Marian plums (Mayongchid) were obtained from an orchard in Nakhonnayok province. The fruits were harvested at 85 days after full bloom, and the fruits weighed between 30 and 50 g per fruit. Two days before harvest, the marian plum fruits were sprayed with distilled water, 1% $CaCl_2$, 2% $CaCl_2$, 1% CaGlu and 2% CaGlu. All solutions were prepared with a small amount of 0.1% Span to improve surface spreading. A calibrated sprayer was used to apply the treatments, with spray volume and spraying distance kept constant. Each fruit was sprayed three times from different angles to ensure full coverage, and the solution was then gently spread by hand to achieve uniform distribution across the fruit surface. After that, the fruits were harvested and delivered to KMITL's postharvest laboratory within 2 h by truck. The fruits were then cleaned with tap water and dried for 1 h. The fruits were arranged into 3 replications, 4 fruits per replicate; after that, all samples were stored at room temperature (26±2ºC, 60-65% RH) for 8 days. The fruits were randomly sampled every 2 days to investigate their physicochemical quality (visual appearance, color attributes, weight loss, firmness, FRAP, DPPH radical scavenging activity, total phenolic compounds, total soluble solids, and total acidity) changes during storage.

### 2.2 Visual appearance and colour measurements

The appearance change during storage of the samples was recorded by taking photographs. The color of the marian plum was measured using a colorimeter (CHROMA METER-CR-400/410, Japan). The color of the marian plum was measured on 2 points of the front and back surfaces. A white tile was used as background during measurement. The lightness (L*), yellowness (b*), hue, and a* values of the marian plums were recorded.

## 2.3 Texture measurement

The firmness of marian plum was measured using a physical property analyzer (EZ Test EZ-SX, Japan). The probes with a diameter of 10 mm at a speed of 0.5 mm $s^{-1}$ were used to measure the firmness of marian plum. The firmness was measured at 2 opposite positions per fruit. The maximum force of measurement was expressed in Newtons (N).

## 2.4 Antioxidant activities assays

Ferric reducing antioxidant power (FRAP) was determined following the method of Benzie and Strain (1996). Marian plum (2 g) was homogenized with 10 mL of distilled water and then centrifuge at 15000 rpm for 10 min. The reaction started when 0.2 mL of supernatant was mixed with 2.8 mL of FRAP reagent (the reagent was a mixture of acetate buffer pH 3, 10 mM 2,4,6-tripyridyl-1,3,5-triazine (TPTZ) and 20 mM ferric chloride hexahydrate in the ratio of 10:1:1), and the mixture was left to stand for at least 30 min. The optical density (OD) at 630 nm wavelength was measured, and the reducing antioxidant activity was calculated using a linear equation of the Trolox standard curve. The data was expressed as mole Trolox equivalents per kg fresh weight (mol $kg^{-1}$).

2,2-diphenyl-1-picrylhydrazyl (DPPH) free radical scavenging activity was determined according to the method of Brand-Williams et al. (1995). Marian plum (2 g) was homogenized with 10 mL of 80% ethyl alcohol and then centrifuged. 2.8 mL of $10^{-3}$ M DPPH in methanol was mixed with 0.2 mL of the supernatant. The absorbance at 517 nm wavelength was immediately measured (OD 0 min), and the mixture was then incubated in a dark condition for 2 min. The OD at 517 nm wavelength was again measured (OD 2 min). DPPH free radical scavenging capacity was carried out by calculating the formula as follows:

$$\text{DPPH radical scavenging activity } (\%) = \frac{OD_{0min} - OD_{2min}}{OD_{0min}} \times 100$$

## 2.5 Malondialdehyde assay

Malondialdehyde (MDA) was determined according to the method of Velikova et al. (2000). Marian plum (2 g) was homogenized with 10 mL of 100 g $L^{-1}$ trichloroacetic acid and then centrifuged at 4°C at 15000 rpm for 10 min. A 2 mL aliquot of 0.67% Thiobarbituric acid was mixed with 0.2 mL of the supernatant. The mixed solution was boiled for 20 min and immediately inserted into ice. The OD at 450 nm, 532 nm, and 630 nm wavelengths were measured. Concentration of MDA was carried out by calculating the formula as follows:

$$c\ (\mu mol/L) = 6.45 \times (OD_{532} - OD_{600}) - 0.56 \times OD_{450}$$

$$MDA\ content = \frac{c \times V}{Vs \times m \times 1000}\ (\mu mol/g)$$

## 2.6 Total phenolic compounds assay

Total phenolic compounds were determined following the method of Slinkard and Singleton (1997). Marian plum (2 g) was homogenized with 10 mL of distilled water and then centrifuged. The supernatant was reacted with 50% (v/v) Folin-ciocalteu reagent and

saturated $Na_2CO_3$ solution in the ratio of 0.2:1:2. The reaction was held at an ambient temperature for at least 30 min, and the OD at 750 nm wavelength was measured. A linear equation of the gallic acid (0,10, 20, 40, 60, 80, 100 and 120 μg/mL) standard curve was used to calculate the concentration of total phenols. The data was expressed as g gallic acid equivalents per kg fresh weight (g $kg^{-1}$).

### 2.7 Total soluble solids, total acidity and BrimA determinations

In total soluble solids assay, marian plum flesh (5 g) was homogenized with 10 mL of distilled water and then centrifuged at 4°C (12000 rpm) for 10 min. The 0.5 mL of enzyme extract were measured using a digital refractometer, repetition 3 times.

In total acidity assay, marian plum flesh (5 g) was homogenized with 10 mL of distilled water and then centrifuged at 4°C (12000 rpm) for 10 min. The 5 mL of enzyme extract was mixed with 3 drops of 0.5% phenolphthalein. Slowly dropped 0.1N NaOH until the solution turned pink and did not fade for 15 s. The amount of sodium hydroxide used was recorded. Total acidity content was calculated by the following formula:

$$\mathrm{TA\%} = \frac{\mathrm{V_{total}} \times \mathrm{C_{NaOH}} \times (\mathrm{V_1} - \mathrm{V_0}) \times \mathrm{f}}{\mathrm{V_s} \times \mathrm{m}}$$

where $V_{total}$ = Total volume of sample (mL)
$C_{NaOH}$ = Concentration of NaOH(mol/L)
$V_1$ = Volume of NaOH used to titrate the sample (mL)
$V_0$ = Volume of NaOH used to titrate the blank (distilled water) (mL)
f = 0.067 (equivalent factor for citric acid)
$V_s$ = Volume of sample used for titration (mL)
m = Sample mass (g)

BrimA was calculated using the formula: BrimA = TSS - (k × TA). The constant k was set at 5 based on prior research to represent the balance between sweetness and acidity (Ncama et al., 2018). All measurements were performed in triplicate to ensure accuracy.

### 2.8 Statistical analysis

All experimental data (3 replicates) were represented as means±standard deviation (SD). Differences between values were assessed for statistical significance by using multivariate analysis (MANOVA), followed by Duncan's multiple range tests using SPSS version 27.0 (SPSS Inc., USA). Differences at $P<0.05$ were considered statistically significant.

## 3. Results and Discussion

#### 3.1 Visual appearance

Figure 1 shows the visual appearance of the marian plums treated with Ca salts compared with the untreated fruits during shelf life at ambient conditions (26±2ºC, 60-65 %RH). After harvest, the fruits of all treatments became more yellow than the fruits at the spraying date, and all Ca treatments postponed visual color development in comparison to the control.

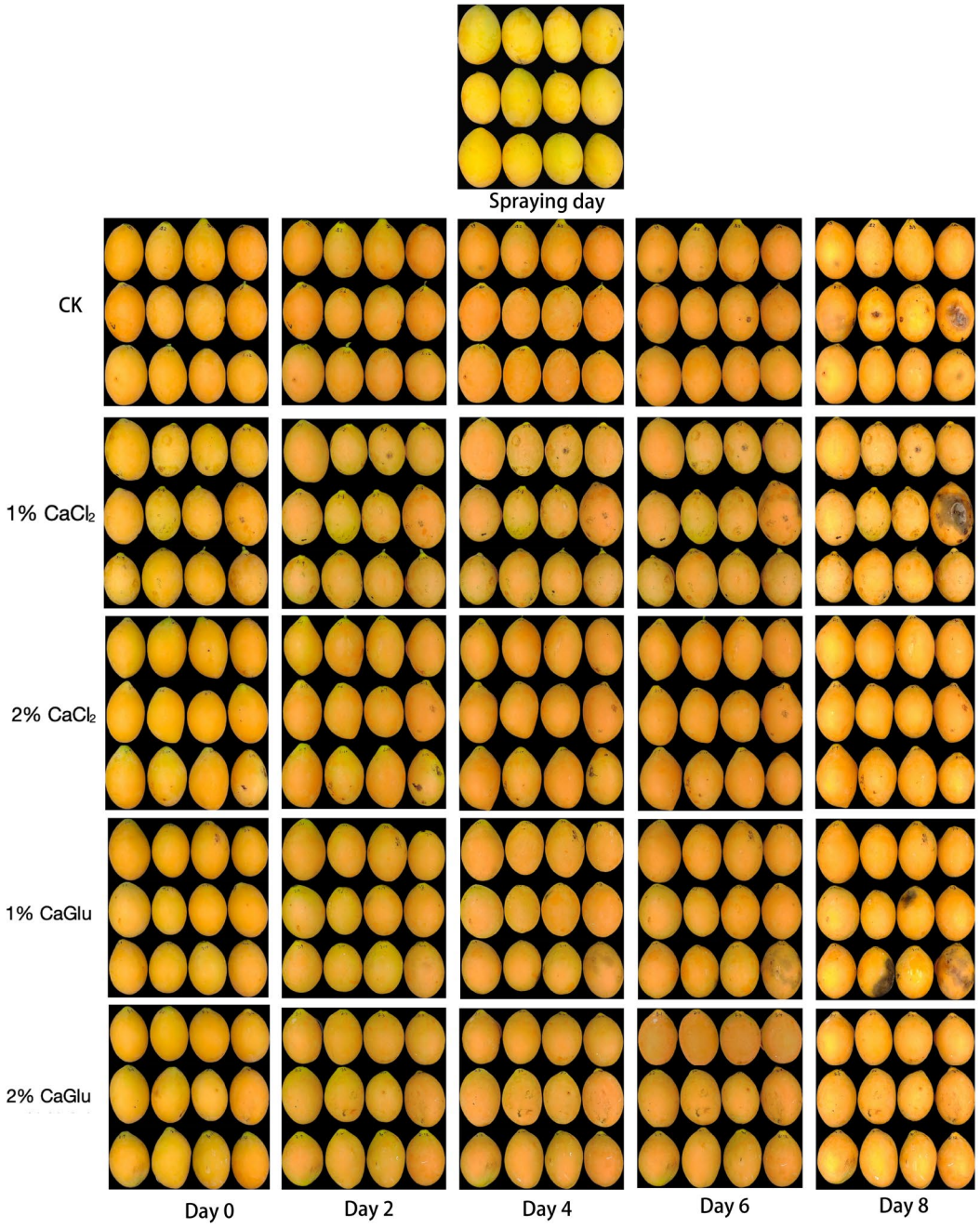


**Figure 1.** Visual appearance of marian plums treated with distilled water (CK), 1% $CaCl_2$, 2% $CaCl_2$ ,1% CaGlu and 2% CaGlu compared with control during storage at room temperature (26±2ºC) for 8 days.

During shelf life for 8 days, the visual color of the control fruits was slight darker than that of all Ca-treated fruits, although the difference was not statistically significant. Moreover, we found that fruit rot was not observed in the 2% $CaCl_2$ and 2% CaGlu-treated fruits during storage. Fruit rot incidence appeared in the control (4 rotted fruits), 1% $CaCl_2$ treated (2 rotted fruits), and 1% CaGlu treated fruits (3 rotted fruits) after storage for 8 days. The results indicate that preharvest spray with $CaCl_2$ and CaGlu, particularly at 2%, postponed the fruit ripening and prevented the fruit rot incidence. Exogenous Ca application maintains the postharvest quality in fruit and vegetables due to the control of respiration rate, the ripening process, and decay incidence (Gao et al., 2019). The results indicate that all preharvest Ca treatments postponed the visual colour development of the marian plums compared to the untreated fruits as shown in the fruits at the spraying date and harvesting date. In addition, during storage, the colour development of the marian plums preharvest-treated wtih Ca salts was lower than that of the control fruits. The application of calcium may indirectly delay pigment formation and color development in fruits by modulating the ripening process (Jaime-Guerrero et al., 2024). Moreover, the results indicated that preharvest treatment with both $CaCl_2$ and CaGlu prevented fruit decay in comparison to the control samples, especially at 2%. It is widely believed that Ca enhances the structural strength of cell walls. This effect contributes to the inhibition of pathogen-derived cell wall-degrading enzymes, ultimately reducing fungal invasion and the incidence of fruit decay (Hocking et al., 2016). Previous work showed that both $CaCl_2$ and CaGlu reduced the incidence of rot in fruit such as jujube fruits (Shanbehpour et al., 2020), litchi (Guo et al., 2023) and nectarines (Liu et al., 2024). In this study, we found that both 2%$CaCl_2$ and 2%CaGlu sprays exhibited comparable results in preserving the visual appearance of marian plums during shelf life at room temperature for 8 days.

### 3.2 Colour attributes

The changes in colour attributes of the marian plums during storage are shown in Figure 2. The L* value exhibits the brightness of the fruit skin. The L* value of all treatments was significantly decreased over storage ($P<0.05$). During storage, the L* value of all Ca salt treatments was comparable to that of the control fruits (Figure 2A). An increased a* value was observed in all treatments during storage at ambient temperature. The increased a* value indicated an increase in the red color of the fruits. The a* value of the control fruits exhibited a significantly higher value than those of all Ca treated fruits over the storage period ($P<0.05$). During 4 days of storage, the a* value of both $CaCl_2$ and CaGlu at 1% was likely to be higher than those of both Ca treatments at 2%. However, all Ca-treated fruits exhibited similar a* values at the end of storage (day 8). For b* value, the raised b* value indicated a change toward yellow in the marian plum. The b* value of all Ca treated fruits was considerably higher than that of the control samples during the first four days of storage ($P<0.05$). On day 6 of storage, the b* values of all Ca salt treatments, except for the 1% CaGlu treatment, were significantly lower than that of the untreated fruit. Even at the end of storage, the b* values of 1% $CaCl_2$ and 2% CaGlu remained considerably higher than the control. The decreased hue value showed the increase in yellowness of the fruits during storage (Figure 2D). Throughout the storage period, the hue values of all Ca treated fruits was considerably higher than that of the control ($P<0.05$). On days 6-8, the $CaCl_2$ treatments showed higher hue values compared to CaGlu treatments, and the concentration of both Ca salts did not influence on the change in hue values. The alterations of color attribute values were linked to the visual color development of the

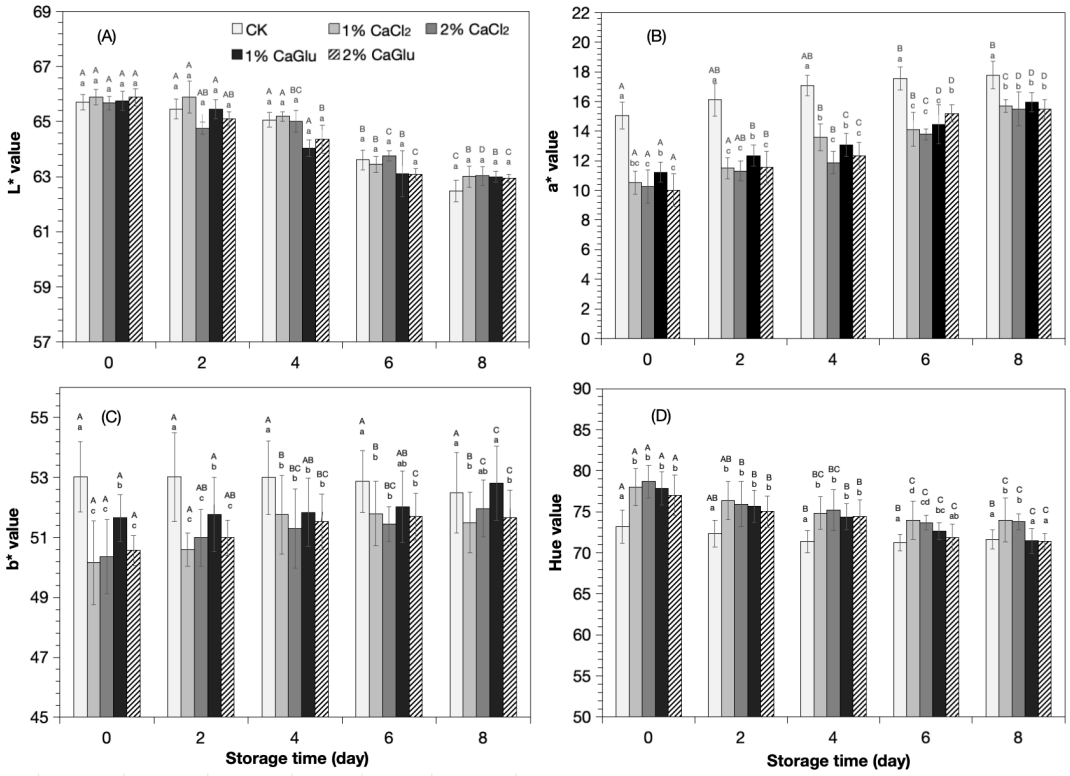


**Figure 2.** L*(A), a* (B), b* (C), hue (D) values of marian plums treated with distilled water (CK), 1% $CaCl_2$, 2% $CaCl_2$ ,1% CaGlu and 2% CaGlu compared with control during storage at room temperature (26±2ºC) for 8 days. The shown data represent the average values of three replications, along with a standard deviation bar. Uppercase letters signify a significant difference in each treatment during storage ($P<0.05$), while lowercase letters indicate a significant variation between treatments on the same day ($P<0.05$).

marain plums as shown in Figure 1. The higher a* and b* values and the lower hue values in the untreated fruits exhibited the higer level of peel yellowness in comparison to the fruits treated with both Ca. The results also indicated that the marian plums subjected to preharvest $CaCl_2$ and CaGlu sprays had lower a* and b* as well as higher hue value than the untreated fruits on the harvesting date (day 0 of storage), which was confirmed by the fruit visual appearance (Figure 1). These results suggest that preharvest treatments with both $CaCl_2$ and CaGlu delayed the fruit ripening process. Moreover, both $CaCl_2$ and CaGlu preharvest treatments retarded the changes in fruit color attributes during storage compared to the untreated fruits. it is widely believed that Ca can delay the postharvest ripening of fruits, thereby slowing down the synthesis and degradation of pigments and maintaining the surface color of postharvest fruits (Aghdam et al., 2012). Supapvanich et al. (2022) reported that t ultrasonic treatment incorporated with CaGlu maintained the green color of guava skin due to delaying the loss of total chlorophyll content. Erbaş and Koyuncu (2021) reported that CaGlu treatment maintained a high L* value and a low a* value of sweet cherries by delaying the ripening. Koju et al. (2024) found that $CaCl_2$ treatment maintained higher L* values and lower a* and b* values of papaya. Similarly,

Netravati et al. (2018) reported that $CaCl_2$ n not only maintained higher L* value in custard apples but also delayed the increase of the a* value and b* value, thus improving the postharvest quality of custard apples. In this study, we found that preharvest $CaCl_2$ and CaGlu sprays delayed the color development of marian plums compared to the untreated fruits. Moreover, $CaCl_2$ was likely to delay the color development rather than CaGlu.

### 3.3 Weight loss and firmness

Fruit weight loss during storage was correlated with physiological metabolism, tissue aging, evapotranspiration-induced water loss, and respiration-induced energy consumption (Latt et al., 2024). The weight loss of marian plums subjected to preharvest $CaCl_2$ and CaGlu sprays during shelf life at room temperature for 8 days is shown in Figure 3A. During the storage period, the untreated fruit had the highest weight loss, and the 2% $CaCl_2$ treatment had the lowest weight loss, which was significantly different compared to other treatments ($P<0.05$). While 1% $CaCl_2$, 1% and 2% CaGlu treated fruits exhibited lower weight loss during the storage period compared with the control. During storage, the firmness of the untreated marian plums was evidently decreased compared to the fruits preharvest-treated with $CaCl_2$ and CaGlu (Figure 3B). At day 2, 1% and 2% CaGlu considerably postponed the marian plums' texture decline as compared to the control ($P<0.05$). On days 4-8, all Ca treatments showed postponement of texture reduction with storage times, and the higher the concentration, the stronger the effect. Fruit softens due to dehydration and cell wall structure degradation during the ripening process, as evidenced by the decrease in firmness (Erbaş & Koyuncu, 2022). However, the findings show that the increased weight loss of the marian plums might not have a direct impact on the fruit softening. It is commonly acknowledged that exogenous Ca application prevents the softening process of postharvest commodities due to the formation of Ca pectate structure (Gao et al., 2019). Ca pectate enhances cell wall strengthening, and furthermore it is not a substrate of polygalacturonase (PG), a cell wall hydrolase (You et al., 2024). This has also been confirmed by previous work in which $CaCl_2$ maintained the texture of some non-climacteric fruits, such as pineapple (Naradisorn et al., 2022), cherries (Erbaş & Koyuncu, 2022), litchi (Guo et al., 2023), and jujube (Shanbehpour et al., 2020). Akhtar et al. (2010) reported that $CaCl_2$ preserved a high level of firmness in loquat and delayed increase in weight loss. Similarly, Erbaş and Koyuncu (2023) reported that CaGlu maintained a higher firmness of cherries with less weight loss in comparison with untreated fruits. In addition, Supapvanich et al. (2022) reported that CaGlu combined with ultrasound effectively delayed the softening of guavas during storage. We found that $CaCl_2$ (2%) and CaGlu (1% and 2%) maintained the firmness of marian plums during the shelf life period. However, the results also showed that $CaCl_2$ was better than CaGlu in controlling weight loss, while CaGlu was better than $CaCl_2$ in maintaining the firmness. This effect may be attributed to the role of $Ca^{2+}$ in promoting stomatal closure (Ruiz et al., 1993). $CaCl_2$, an inorganic calcium salt of high solubility, releases $Ca^{2+}$ more rapidly than CaGlu (Akhtar & Rab, 2014). The influence of exogenous $CaCl_2$ and CaGlu on stomatal behavior has been documented in previous studies (Huang et al., 2019; Mimata et al., 2022). However, the present findings indicate that $CaCl_2$ is more effective in delaying the onset of increased weight loss in marian plums compared to CaGlu. On the other hand, the slower release of $Ca^{2+}$ from CaGlu may allow for prolonged calcium retention in the cell wall matrix, which could contribute to better firmness preservation in CaGlu–treated fruits compared to those treated with $CaCl_2$.

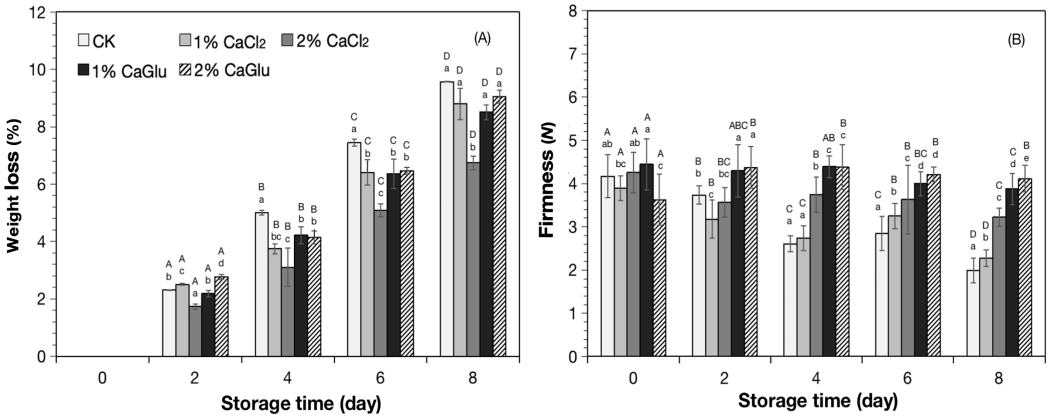


**Figure 3.** Weight loss(A) and firmness (B) of marian plum treated with distilled water (CK), 1% $CaCl_2$, 2% $CaCl_2$ ,1%CaGlu and 2%CaGlu compared with control during storage at room temperature (26±2ºC) for 8 days. The shown data represent the average values of three replications, along with a standard deviation bar. Uppercase letters signify a significant difference in each treatment during storage ($P<0.05$), while lowercase letters indicate a significant variation between treatments on the same day ($P<0.05$).

## 3.4 MDA content

Figure 4 illustrates the changes in MDA content, which serves as an indicator of lipid peroxidation in cell membranes and oxidative stress. During storage for 4 days, the MDA content did not change much, indicating that the cell membranes of the marian plums were relatively well preserved during this period. On day 6, the MDA content in the control, 1% $CaCl_2$, and 2% CaGlu treatments increased significantly, whereas the MDA content in the 2% $CaCl_2$ and 1% CaGlu treatments remained at levels similar to the earlier stages and significantly lower than that of the control ($P<0.05$). By day 8, the MDA content in all treatments had increased significantly, but all Ca treatments still had lower levels than the untreated fruits. It is widely recognized that MDA, as a marker of lipid peroxidation, reflects the extent of oxidative damage to cell membranes (Gaweł et al., 2004). Ca enhances the stability of cell membranes and cell walls by binding with phospholipids, reducing the reaction between lipid peroxidation free radicals and unsaturated fatty acid molecules, thereby indirectly decreasing MDA production (Balantič et al., 2022). In this study, both $CaCl_2$ and CaGlu treatments obviously delayed the increase of MDA levels in marian plums compared to the untreated fruits during storage. This finding was consistent with previous reports. Weng et al. (2022) observed that Ca ions stabilized cell membrane structures, thereby mitigating lipid peroxidation caused by extended storage. Similarly, Xie et al. (2014) reported that $CaCl_2$ reduced MDA content of cowpeas. In addition, Youryon et al. (2018) reported that both $CaCl_2$ and CaGlu evidently reduced MDA production in queen pineapples during cold storage by inhibiting lipid peroxidation of cell membranes. Moreover, Supapvanich et al. (2022) reported that CaGlu combined with ultrasonic treatment postponed the increase in MDA content in pink guavas during storage. In addition, they also suggested that the increase in MDA was also linked to the softening of the guavas during storage. In this study, we found that the lower MDA concentrations in marian plums subjected to all preharvest Ca treatments were linked to the firmness of the

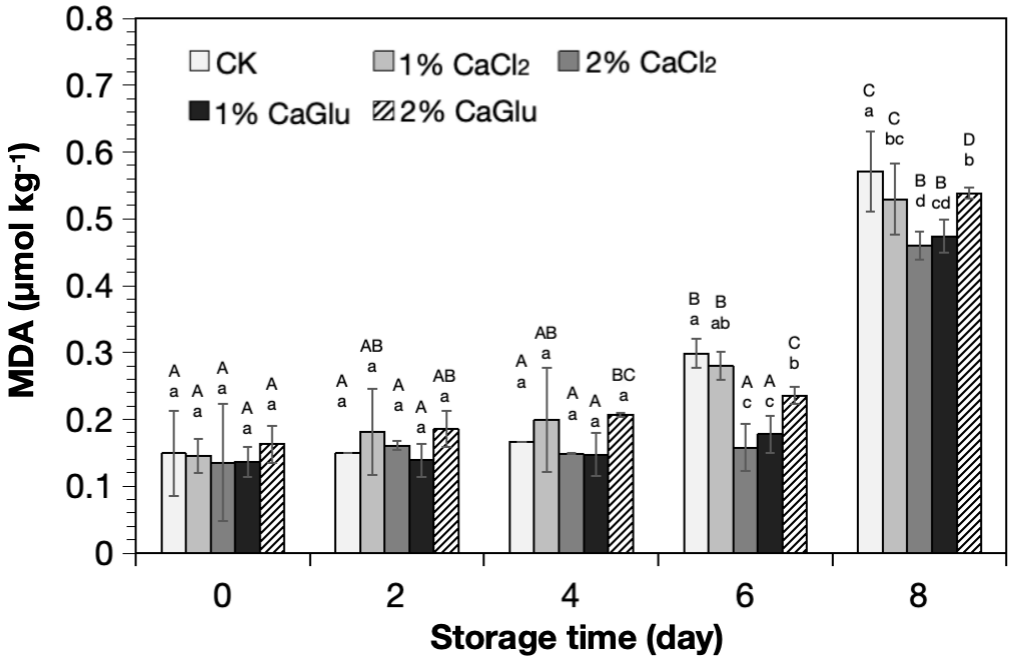


**Figure 4.** Malondialdehyde (MDA) content of marian plum treated with distilled water (CK), 1% $CaCl_2$, 2% $CaCl_2$ , 1% CaGlu and 2% CaGlu compared with control during storage at room temperature (26±2ºC) for 8 days. The shown data represent the average values of three replications, along with a standard deviation bar. Uppercase letters signify a significant difference in each treatment during storage ($P<0.05$), while lowercase letters indicate a significant variation between treatments on the same day ($P<0.05$).

fruits compared to the untreated fruits. This indicated that the firmness reduction of marian plums during storage was not only related to cell wall degradation but was also related to membrane dysfunction. The effect of Ca applications to maintain the marian plum's firmness might be associated with the maintenance of cell wall structure as well as membrane integrity.

### 3.5 TSS, TA, and ripening index (Brim A)

The changes in TSS, TA, and Brim A of marian plums treated with $CaCl_2$ and CaGlu during the shelf life period are shown in Figure 5. It is generally acknowledged that TSS and TA indicate sweetness and sourness in fruits, respectively. Recently, BrimA has been accepted to serve as an organoleptic parameter that shows a strong correlation with the sweetness and flavour of fruit, aligning closely with the prediction of human taste perception (Ncama et al., 2018). A low BrimA indicates more sourness, while a high BrimA indicates more sweetness. It was found that the TSS content of the untreated fruits increased following the storage period, and the TSS of the 1% $CaCl_2$, 1% CaGlu, and 2% CaGlu treatments showed a slight increase during the storage period and were likely to be lower than that of untreated fruits. Whereas TSS of the fruits treated with 2% $CaCl_2$ seemed constant over the storage period. The TA content of the control fruits declined over the

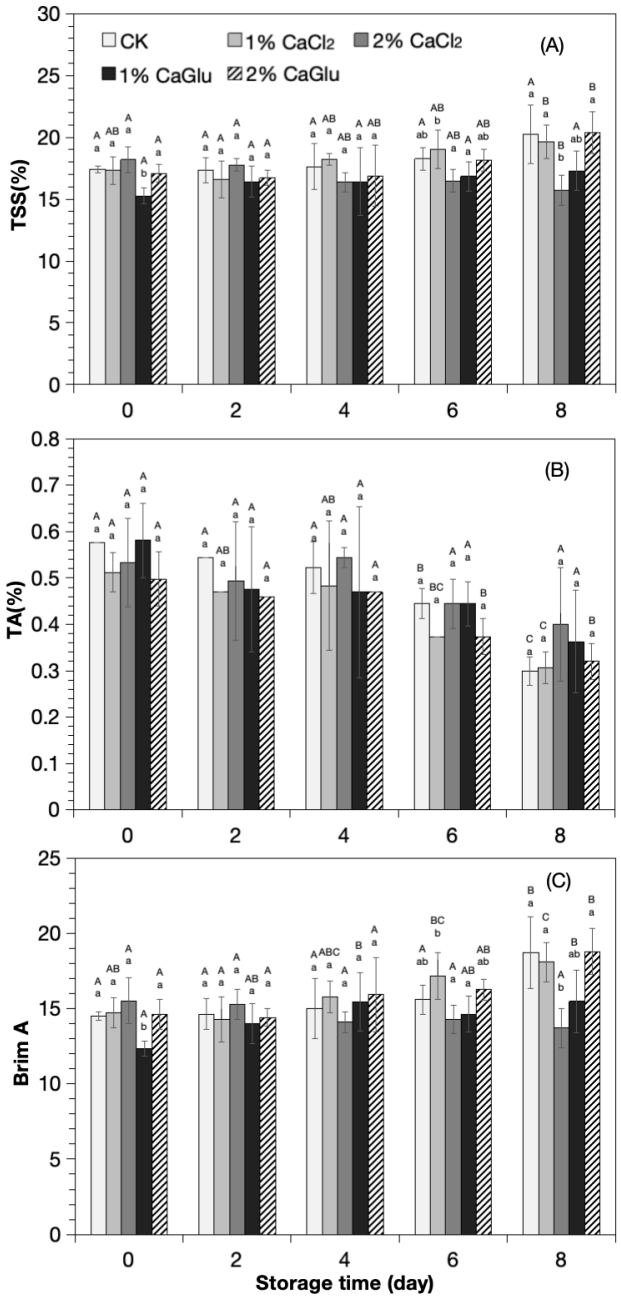


**Figure 5.** TSS (A), TA (B), BrimA (C) of marian plums treated with distilled water (CK), 1% $CaCl_2$, 2% $CaCl_2$ , 1% CaGlu and 2% CaGlu compared with control during storage at room temperature (26±2ºC) for 8 days. The shown data represent the average values of three replications, along with a standard deviation bar. Uppercase letters signify a significant difference in each treatment during storage ($P<0.05$), while lowercase letters indicate a significant variation between treatments on the same day ($P<0.05$).

storage period. During storage for 6 days, there was no significant difference in the TA content of the fruits with all Ca salt treatments compared to the control fruits. On the other hand, it was observed the TA content was higher in the 2% $CaCl_2$ treatment than other treatments on day 8. The BrimA of the fruits treated with 2% $CaCl_2$ seemed constant and lower than that of untreated fruits over the storage period. The BrimA of the control and other Ca treated fruits increased following the storage period. The results indicate that the 2% $CaCl_2$ treatment more effectively suppressed the decline in total acidity compared to both CaGlu and the control treatments. This effect may be attributed to the $Ca^{2+}$ released from $CaCl_2$ influencing the activity of enzymes involved in organic acid metabolism (Zhang et al., 2024). $Ca^{2+}$ can enhance the activity of enzymes related to sugar and acid metabolism in fruits, including phosphoenolpyruvate carboxylase (PEPC) and malate dehydrogenase (MDH), thereby promoting the accumulation of organic acids such as malic acid and citric acid (Li et al., 2024). Additionally, Erbaş and Koyuncu (2022) reported that $CaCl_2$ delayed the increase in TSS content and the decrease in TA content during the storage period of cherries, thereby maintaining the post-harvest taste of cherries. Lysiak et al. (2008) suggested that 2% $CaCl_2$ treatment maintained a high level of TA content in peaches (*Prunus persica*) during storage. Qiu et al. (2022) also reported that exogenous Ca treatment delayed the increase of TSS and the decrease of TA of *Annona squamosa*. Similarly, Erbaş and Koyuncu (2023) reported that CaGlu treatment could delay the TA loss of cherries during storage.

## 3.6 Total phenolic compounds and antioxidant capacity

Figure 6 illustrates the impact of treating marian plums with $CaCl_2$ and CaGlu prior to harvesting on the levels of total phenolic compounds and antioxidant activities, such as FRAP and free radical scavenging activity, during storage. On the initial day of shelf life, the FRAP and total phenol content of 1% $CaCl_2$, 2% $CaCl_2$, and 2% CaGlu-treated marian plums were significantly higher than those of the control and 1% CaGlu-treated samples ($P<0.05$). During the shelf life of 6 days, the FRAP and total phenolic compounds of all Ca-treated groups were likely higher than those of the control. However, on the last day of shelf life, both the FRAP and total phenolic compounds of all Ca-treated fruits were not significantly different when compared to those of control fruits. DPPH radical scavenging activity of all samples was comparable on the initial day of shelf life. During the 4-day shelf life, the DPPH radical scavenging activity of fruits treated with 2% $CaCl_2$ was significantly higher than that of the control fruits. On day 6, the DPPH radical scavenging activity of 2% $CaCl_2$-treated fruits increased to significantly higher level than that of the control fruits ($P<0.05$), and the DPPH radical scavenging activity of both the 1% and 2% CaGlu-treated fruits was likely to be higher than that of the control fruits. On the last day of shelf life, the DPPH radical scavenging activity of 2% $CaCl_2$ and both CaGlu-treated fruits were higher than that of the control and 1% $CaCl_2$-treated fruits. These indicate that preharvest treatment of Ca salts could enhance antioxidant activity in marian plums during shelf life. CaGlu was likely to induce DPPH radical scavenging activity rather than $CaCl_2$.

Previous research has shown that Ca controls the antioxidant enzyme system by sending signals, inducing the synthesis of phenolic compounds, and keeping cell structures stable. This reduces the impact of free radical-induced oxidative stress and subsequently boosts the antioxidant capacity of fruits (Ermak & Davies, 2002; Che et al., 2024). Several previous works reported that exogenous $CaCl_2$ treatment enhanced certain secondary metabolites and antioxidant capacity in many kinds of fruits, such as jujube fruits

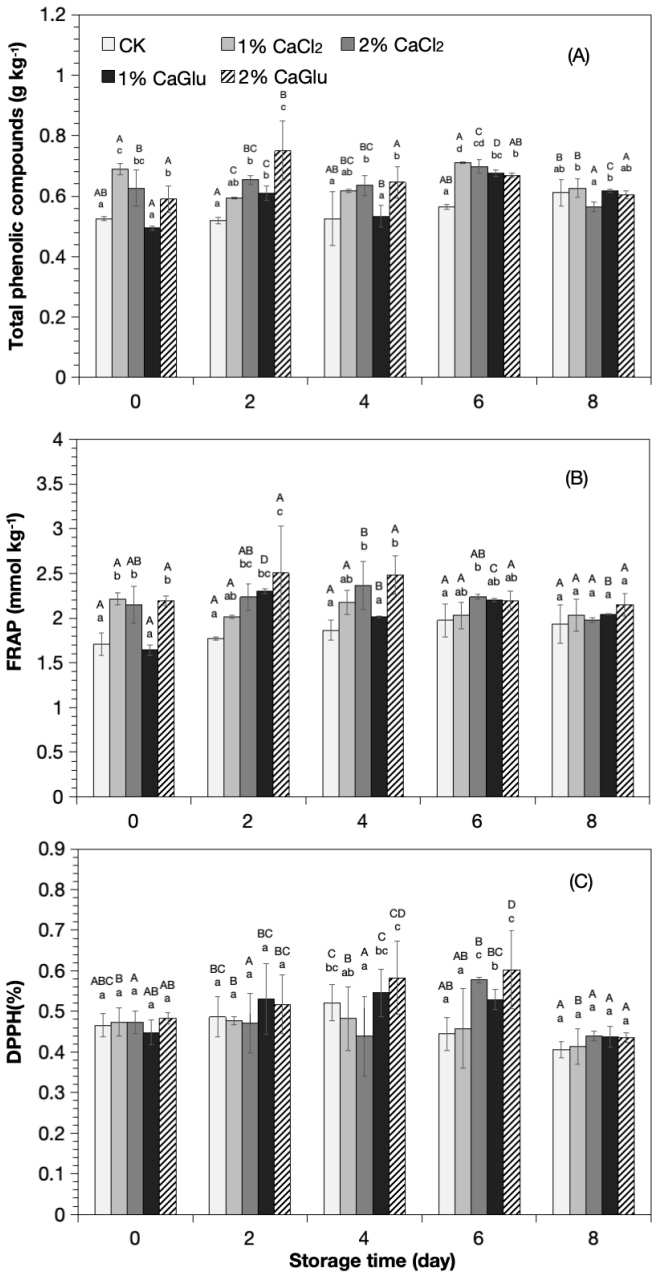


**Figure 6.** Total phenols (A), FRAP (B), DPPH (C) of marian plums treated with distilled water (CK), 1% $CaCl_2$, 2% $CaCl_2$ , 1%CaGlu and 2%CaGlu compared with control during storage at room temperature (26±2ºC) for 8 days. The shown data represent the average values of three replications, along with a standard deviation bar. Uppercase letters signify a significant difference in each treatment during storage ($P<0.05$), while lowercase letters indicate a significant variation between treatments on the same day ($P<0.05$).

(Shanbehpour et al., 2020), pineapples (Naradisorn et al., 2022), nectarines (Liu et al., 2024), and tomatoes (Mazumder et al., 2021). Also, Youryon et al. (2018) found that CaGlu, not $CaCl_2$, could increase the antioxidant activity and lower the membrane permeability and membrane lipid peroxidation of "Queen" pineapples during cold storage. These indicate that Ca salts effectively delayed the early-stage oxidative reactions of marian plums and enhanced their antioxidant capacity during shelf life.

### 3.7 Pearson's square correlation

As the results shown above, both $CaCl_2$ and CaGlu preharvest treatments, especially at 2%, evidently preserved visual appearance and prevented fruit decay. Ca application also clearly impacted on firmness maintenance, TSS, TA, BrimA and antioxidants. Table 1 and Table 2 indicate the correlation of each parameter in untreated and Ca (2% $CaCl_2$ and 2% CaGlu) treated marian plums, respectively. The results in Table 1 indicate that the firmness of the untreated fruits was significantly negative correlated with the weight loss ($R^2$= -0.894) and MDA content ($R^2$= -0.708) ($P<0.01$). It is widely accepted that weight loss, cell wall degradation, and membrane dysfunction are key factors of fruit softening. Previous work reported that the softening of marian plums was concommitant with increased cell wall degradation (Wattanakeeboot & Chanasut, 2021). The results showed that the loss of marian plum firmness (Figure 3B) was also closely associated with increased weight loss (Figure 3A) and MDA content (Figure 4). In addition, we also found that firmness was significantly positive correlated with TA ($P<0.01$) and negatively correlated with BrimA and FRAP ($P<0.05$). These might be associated with the ripening increase during shelf life. The change in the taste of fruit is commonly recognised to be associated with the TSS and TA content. The alteration of BrimA has been accepted as a potential parameter indicating the overall taste of fruits (Ncama et al., 2017). The outcomes showed the BrimA was significantly positive correlated with TSS ($R^2$ = 0.982, $P<0.01$) and significantly negative correlated with TA ($R^2$ = - 0.796, $P<0.01$). Moreover, BrimA showed a significant positive correlation with weight loss ($R^2$ = 0.647, $P<0.01$) and MDA content ($R^2$ = 0.692, $P<0.01$) as well as significantly negative correlated with firmness ($R^2$ = - 0.591, $P<0.05$). Previous work reported that increased weight loss and tissue softening were evidently related with increased sweetness in fruits due to the ripening progress (Kassebi et al., 2023). For antioxidant activity, the results showed that there was no significant correlation between FRAP and DPPH levels in the untreated fruits. FRAP exhibited a significantly negative correlation with the firmness of the fruits ($R^2$ = - 0.583, $P<0.05$) and a positive correlation with the weight loss ($R^2$ = 0.594, $P<0.05$). DPPH was significantly negative correlated with MDA ($P<0.05$) and total phenol content ($P<0.05$), supporting the role of antioxidant compounds in mitigating oxidative reaction of lipid membrane structure. Furthermore, DPPH was found to be positively correlated with TA ($P<0.01$). It is recognised that NaOH titration can be used to measure the content of ascorbic acid, which is known to have free radical scavenging properties.

The results in Table 2 indicate that Ca treatment significantly altered the relationships between firmness and several parameters compared to untreated fruits. After Ca-treatment, the firmness of Ca treated marian plums was no longer significantly correlated with weight loss and MDA content. This might be because Ca application mitigated the negative effects of water loss and lipid membrane peroxidation. Moreover, we found that the firmness was significantly positively correlated with FRAP, total phenolic compounds and DPPH levels ($P<0.01$). As the results shown in Figure 6, the FRAP level

**Table 1.** Correlation between each parameter in untreated marian plums

| CK | L value | H value | Weight loss | Firmness | MDA | TA | TSS | BrimA | TP | FRAP | DPPH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L value | 1 | | | | | | | | | | |
| H value | 0.438 | 1 | | | | | | | | | |
| Weight loss | -0.896** | -0.702** | 1 | | | | | | | | |
| Firmness | 0.756** | 0.562** | -0.894** | 1 | | | | | | | |
| MDA | -0.868** | -0.329 | 0.834** | -0.708** | 1 | | | | | | |
| TA | 0.873** | 0.476 | -0.895** | 0.778** | -0.936** | 1 | | | | | |
| TSS | -0.584* | -0.31 | 0.516* | -0.484 | 0.558* | -0.666** | 1 | | | | |
| BrimA | -0.697** | -0.373 | 0.647** | -0.591* | 0.692** | -0.796** | 0.982** | 1 | | | |
| TP | -0.652** | -0.204 | 0.601* | -0.494 | 0.68** | -0.543* | 0.339 | 0.414 | 1 | | |
| FRAP | -0.525* | -0.393 | 0.594* | -0.583* | 0.492 | -0.473 | 0.078 | 0.184 | 0.278 | 1 | |
| DPPH | 0.688** | -0.084 | -0.45 | 0.331 | -0.616* | 0.531* | -0.208 | -0.305 | -0.639* | -0.229 | 1 |

**Table 2.** Correlation between each parameter in the 2% calcium salts treated marian plums

| Ca | L value | Hue value | Weight loss | Firmness | MDA | TA | TSS | BrimA | TP | FRAP | DPPH |
|---|---|---|---|---|---|---|---|---|---|---|---|
| L value | 1 | | | | | | | | | | |
| Hue value | 0.764** | 1 | | | | | | | | | |
| Weight loss | -0.893** | -0.904** | 1 | | | | | | | | |
| Firmness | 0.309 | 0.081 | -0.13 | 1 | | | | | | | |
| MDA | -0.712** | -0.584** | 0.792** | -0.268 | 1 | | | | | | |
| TA | 0.634** | 0.682** | -0.725** | -0.044 | -0.699** | 1 | | | | | |
| TSS | -0.183 | -0.229 | 0.234 | 0.33 | 0.281 | -0.298 | 1 | | | | |
| BrimA | -0.316 | -0.369* | 0.383** | 0.309 | 0.419* | -0.506** | 0.974** | 1 | | | |
| TP | 0.129 | -0.06 | -0.093 | 0.323 | -0.408* | 0.161 | -0.228 | -0.244 | 1 | | |
| FRAP | 0.205 | 0.002 | -0.167 | 0.433** | -0.361* | 0.216 | -0.143 | -0.18 | 0.591** | 1 | |
| DPPH | 0.008 | -0.122 | -0.043 | 0.322 | -0.415* | -0.022 | -0.053 | -0.043 | 0.342 | 0.348 | 1 |

of the marian plums was enhanced by both 2% $CaCl_2$ and 2% CaGlu. The increased FRAP, total phenolic compounds, and DPPH levels from Ca treatments were concomitant with the firmness preservation. Moreover, Ca also reduced the negative correlation between MDA and fruit firmness. These results indicate that Ca not only strengthens cell wall structure, but also mitigates membrane lipid peroxidation due to the enhancement of antioxidants. The BrimA of the Ca-treated fruits showed a significantly positive correlation with TSS ($R^2$ = 0.974, $P<0.01$), MDA ($R^2$ = 0.419, $P<0.05$), and weight loss ($R^2$ = 0.383, $P<0.01$), as well as a significantly negative correlation with TA ($R^2$ = -0.506, $P<0.01$). However, the correlations were weakened compared to untreated fruits, indicating that Ca treatment postponed the alteration of the fruit taste. Moreover, we also found that TA of the Ca-treated fruits was significantly negative correlated with MDA content ($P<0.01$). In antioxidant activities, a significantly positive correlation between FRAP and total phenolic compounds ($P<0.05$) was observed in the Ca-treated fruits compared to the untreated

fruits. The DPPH, FRAP, and total phenolic compounds of the Ca-treated fruits had a significantly negative correlation with MDA content. These indicate that preharvest Ca treatments (both 2% $CaCl_2$ and 2% CaGlu) could preserve the postharvest quality as well as enhance the resistance to oxidative responses in marian plums over shelf life.

## 4. Conclusions

According to the results, both $CaCl_2$ and CaGlu preharvest treatments (2 days prior to harvest) preserved the visual appearance and postponed the fruit colour development of marian plums during storage. Both calcium treatments at 2% inhibited fruit decay during shelf life of 8 days. The preharvest calcium treatments (both $CaCl_2$ and CaGlu) delayed the increase in weight loss and fruit softening. The 2% CaGlu treatment preserved the fruit firmness better than other calcium treatments. Both 2% $CaCl_2$ and 2% CaGlu retarded membrane lipid peroxidation. This was associated with the fruit firmness maintenance in the calcium treated fruits. Preharvest Ca treatments delayed the increases in TSS and BrimA as well as postponed the decrease in TA compared to the control. The total phenolic content and antioxidant capacities, including FRAP and DPPH, were enhanced by all calcium treatments. The correlation analysis indicated that preharvest calcium treatments could preserve the postharvest quality of the marian plums, especially texture maintenance and antioxidant improvement, compared to the untreated fruits. These results suggest that CaGlu and $CaCl_2$ preharvest treatment, especially at 2%, are alternative approaches for maintaining the postharvest quality of marian plums during shelf life at room temperature.

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## 6. Authors' Contributions

Li Da: Writing – Writing – original draft; Investigation; Methodology; Formal analysis; Data curation. Sirima Sunthusamran: Supervision; Conceptualization. Pannipa Youryon: Supervision. Wen Bo: Supervision. Suriyan Supapvanich: Writing – Writing – original draft; Conceptualization; Visualization; Supervision; Data curation; Funding acquisition; Writing – review & editing. Chairat Techavuthiporn: Supervision; Conceptualization

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## 7. Conflicts of Interest

There are no conflicts of interest.

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